Technical Memorandum

Summary of Cooking Loss Studies and Data Evaluation

This Technical Memorandum summarizes the results of a technical review and analysis of literature related to cooking loss of hydrophobic organic chemicals in fish. Loss of hydrophobic chemicals of potential concern (COPC) upon cooking is a recognized phenomenon and can have a significant effect on the calculated COPC exposure dose from tissue consumption by humans. Numerous published studies have evaluated contaminant loss from fish tissue as a result of cooking, many of which have been summarized in scientific literature reviews (Sherer and Price 1993, Wilson et al. 1998, Zabik and Zabik, 1999), as well as agency guidance on assessing contaminants in fish consumption advisories (USEPA 2000). This Technical Memorandum summarizes the CPG's review and analysis of relevant studies in anticipation of further discussions with USEPA Region 2 on this topic, as it relates to the human health risk assessment (HHRA) for the LPRSA.[1]

The goals of the CPG's evaluation are as follows:

- Perform an updated literature review to include more recent studies on cooking loss in fish, focusing on lipophilic organic chemicals,
- Evaluate relevant data on a consistent basis that accounts for changes in tissue mass as a result of cooking processes – this is most commonly done by considering the mass of COPC in the edible tissue before and after cooking,
- Identify studies with sufficient data for quantitative analysis to determine the range and midpoint on a chemical- and cooking method-specific basis, and
- Evaluate the importance of other specific factors influencing the extent of cooking losses, such as species, skin-on versus skin-off preparation, lipid content, and cooking duration and temperature.

Background

In the July 11, 2011 comments on the revised Risk Analysis and Risk Characterization (RARC) Plan for the LPRSA, USEPA Region 2 specified cooking loss factors to be used in the LPRSA HHRA for the reasonable maximum exposure (RME) and central tendency exposure (CTE) fish consumption scenarios. These are identified in the final RARC Plan (Windward and AECOM, in prep), and are summarized below:

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[1] During dispute resolution on the Risk Analysis and Risk Characterization (RARC) Plan, USEPA agreed to discuss with the CPG outside of the dispute resolution process the topic of cooking loss as it relates to the baseline human health risk assessment for the Lower Passaic River Study Area (LPRSA), with the stipulation that cooking loss factors be limited to the Central Tendency Exposure (CTE) scenario.

Cooking loss factors for fish

Chemical	RME (%)	CTE (%)
DDD	0	30
DDE	0	35
DDT	0	30
Chlordane	0	33
Dieldrin	0	30
Dioxins	0	49
PCBs	0	20 (midpoint of 0 to 40%)
Mercury	0	0

CTE – central tendency exposure
DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure

USEPA's cooking loss factors for all COPCs except PCBs are taken from the agency's draft Focused Feasibility Study (FFS) for the LPRSA (Battelle 2007), which used the studies reported in *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Appendix C, Dose Modifications Due to Food Preparation and Cooking* (USEPA 2000), all of which were published prior to 1997. The analysis conducted for the draft FFS involved aggregating all reported losses listed in Appendix C of USEPA (2000) by chemical and calculating summary statistics, including the minima and maxima, median, mean and 90th percentile. The cooking loss values selected by USEPA are medians of the respective COPC-specific data sets.

USEPA's cooking loss factors for PCBs are the values derived by the agency for the Hudson River HHRA (TAMS/Gradient 2000). The PCBs cooking loss factors used in the Hudson River HHRA were based on a review of 12 studies (also included in the CPG's review), that addressed a variety of cooking methods, preparation methods (trimmed/untrimmed, skin-on/skin-off), and species. The range of PCB losses reported (expressed as percent loss based on total PCB mass before and after cooking) was less than zero (i.e., net gain) to 74%[2]. While no statistics or percentiles were provided, a CTE cooking loss value of 20% was selected, with an RME of 0% and a low-end exposure value of 40% (TAMS/Gradient 2000), for use in parameter uncertainty analysis.

Summary of Updated Literature Review

A total of 34 relevant studies were identified, as summarized in Table 1. Of the 34 relevant studies identified, 29 address PCBs as mixtures or Aroclors, two address coplanar or so-called "dioxin-like" PCB congeners, 13 address one or more DDx isomers, and nine address one or more dioxin and furan congeners. The studies address a variety of fish species, including striped bass, carp, trout, bass, catfish, perch, flounder, salmon, walleye, and bluefish. A variety of cooking methods are represented, including

[2] Net gains are attributed to experimental measurement error and indicate zero/negligible loss (TAMS/Gradient 2000).

baking/roasting, broiling, grilling, boiling, poaching, pan frying, deep frying, microwaving, and smoking. Four of the 34 studies are review articles; where possible, the original studies and data were used in this evaluation. The full list of studies reviewed is presented in the references. A number of other studies related to cooking loss in other foodstuffs (e.g., beef) and other contaminants, such as inorganics, were also identified. However, because this analysis focuses on lipophilic organic compounds and fish, they are not included.

The pool of studies was narrowed to 17 that used a relevant and appropriate experimental method and presented changes in raw and cooked fish tissue COPC levels on a mass basis or provided sufficient data for calculating mass loss of COPC (see Table 2). Comparison of concentrations in raw and cooked fish alone neglects the change in tissue mass that occurs, which is often significant. Therefore, this evaluation addresses the change in COPC levels on a consistent, mass basis. The percentage of COPC mass lost during cooking was calculated as follows:

$$\frac{\text{COPC mass in uncooked fillet} - \text{COPC mass in cooked fillet}}{\text{COPC mass in uncooked fillet}} \times 100$$

For studies that did not report loss on this basis, but provided the necessary data (e.g., pre- and post-cooking tissue concentrations and weights, or weight loss factor), it was possible to calculate loss on a mass basis from the data provided.

The mass-based method of quantifying cooking loss is consistent with numerous studies, including those of Zabik and colleagues (1979, 1995, 1995a,b, 1996), Stachiw et al. (1988), Sherer and Price (1993), Moya et al. (1998), Wilson et al. (1998), and Wang and Harrad (2000). It is also the approach used in the PCB cooking loss analysis for the Hudson River HHRA. For one study (Smith et al. 1973), it was necessary to calculate mass loss differently due to the type of data provided. For Smith et al. (1973), mass loss was calculated following the method described in Sherer and Price (1993), as follows:

$$\frac{\text{Mass of COPC in drippings}}{\text{COPC mass in cooked fillet} + \text{COPC mass in drippings}} \times 100$$

The mass of COPC in drippings and cooked fillet was calculated as:

$$M_{COPC} = C_{COPC} \times F \times M_r$$

Where:

M_{COPC}	=	Mass of COPC in fillet or drippings in ug
C_{COPC}	=	Concentration of COPC in ug/g fat in fillet or drippings
F	=	Percentage of fat in fillet or drippings
M_r	=	Mass of fillet or drippings in g

Studies that reported results solely on a TEQ basis were not included, since actual changes in mass are obscured by weighting of individual congener results on the basis of toxicity.

For each study, Table 2 presents the reported or calculated percent mass loss values for three key COPCs (PCBs, DDx compounds, and dioxins and furans) by each of seven cooking methods with available data: 1) deep fry, 2) pan fry, 3) bake/roast, 4) broil/grill, 5) boil/poach, 6) microwave, and 7) smoke. The cooking methods, bake and roast, were considered sufficiently similar to be grouped for the purposes of this analysis, as were broil and grill (including charbroil), and boil and poach. The cooking methods with the most data points are broil/grill, bake/roast, pan fry, and deep fry. When all cooking methods are combined, the number of data points identified for each of the three COPCs is as follows: PCBs n = 79; dioxins and furans n = 12; and DDx n = 70. Table 3 presents mass loss results by cooking method for the three COPCs, as well as summary statistics and percentiles.

<u>Analysis of Outliers and Extreme Values</u>

An analysis was performed on the three combined cooking method data sets to determine if any individual data points may be statistical outliers or extreme values. Outliers and extreme values were defined using the Interquartile Range (IQR), which is equal to the difference between the 75th and 25th percentiles of the dataset. The IQR approach to the determination of outliers and extreme values has been referred to in USEPA (2006). Outliers and extreme values were defined as follows:

1. Outliers: Those values that were less than (25th percentile – 1.5 x IQR) or greater than the (75th percentile + 1.5 x IQR).
2. Extreme values: Those values that were less than (25th percentile – 3 x IQR) or greater than the (75th percentile + 3 x IQR).

The results of the outlier and extreme value evaluation are also presented in Table 3. For each COPC dataset, those values determined to be outliers are highlighted yellow and those values determined to be extreme values are highlighted red. One value of 100% loss of dioxin following smoking (Zabik and Zabik 1995) was identified as an extreme value. Two negative values for PCBs and five high end values for DDx compounds were identified as outliers. Figure 1 presents box and whisker plots with the outliers and extreme value identified by yellow and red dots, respectively.

Summary statistics and percentiles were calculated with and without the extreme values and outliers. As shown in Table 4, midpoint values change only slightly when the extreme value and outliers are removed. Figure 2 presents the range and median cooking loss value by cooking method for each of the three COPCs (all values are included in Figure 2 with the exception of the extreme value of 100% loss of dioxin for smoking).

General observations include the following:

- Even when expressed on a consistent mass loss basis, results are variable, with percent loss values ranging as high as 70-80% and as low as zero for the same COPC and cooking method;

- For the study that reported an increase in mass after baking and broiling (Moya et al. 1998), the observations generally coincide with low initial COPC concentrations, and are likely an artifact of measurement error rather than a true net gain in COPC mass;

- Median losses are generally in the range of 20 to 50% for typical cooking methods (i.e., pan frying, baking, broiling, deep frying), and consistent differences in mass loss between cooking methods are not apparent;

- Based on the observation that the cooking loss results for each of the three categories of COPCs all fall into the same wide range, the case could be made for combining all studies into a single category of lipophilic organochlorinated compounds and assigning one cooking loss factor to the entire set of compounds;

- Two studies examined the cooking loss of PCDDs, PCDFs, and coplanar PCB congeners in the same samples of fish under the same experimental protocols (Hori et al., 2005; Schecter et al., 1998). Within each of these studies, the cooking losses of the PCDDs, PCDFs, and coplanar PCBs were nearly the same. Hence, the data indicate that these congeners comprise a group of compounds, which should be assigned the same cooking loss factor;

- In keeping with EPA's approach of differentiating cooking losses between COPC classes, a similar approach was taken here and median and mean cooking loss values were computed with the three COPC classes;

- Combining results for each COPC across all cooking methods and all data, the median (and *mean*) losses are: 30% (*32%*) for total PCBs; 50% (*53%*) for dioxins, furans and coplanar PCBs; and 32% (*34%*) for DDx; and

- When statistical outliers and extreme values are removed, the median (and *mean*) losses change minimally: 30% (*33%*) for total PCBs; 48% (*48%*) for dioxins, furans and coplanar PCBs; and 31% (*31%*) for DDx.

There are a number of potential causes for the variability observed in the data, including differences in the specifics of the cooking methods (e.g., time, temperature), differences in fillet processing (e.g., trimming and thickness, part of body) and fillet geometry, variability in COPC concentrations between fish used within the same study, low initial COPC concentrations for some studies (e.g., less than 10-fold margin between concentration and the limit of detection (LOD)), and differences in extraction methods for raw and cooked tissues.

Other observations based on a review of the available data include that initial COPC concentration in the fish tissue does not appear to be a controlling factor when losses are reported on a mass basis. A relationship between skin removal or retention and cooking loss is not consistently apparent, although some studies did find greater loss with skin removal (Bayen et al. 2005; Salama et al. 1998; Zabik et al. 1979). Some studies suggest that higher internal temperatures and longer cooking times result in higher losses (Stachiw et al. 1998; Zabik et al. 1982). Last, while some data support a correlation between lipid loss and COPC loss during cooking (e.g., Bayen et al. 2005), analysis by others suggests that a loss of lipid is not consistently correlated with COPC loss (Wilson et al. 1998; Moya et al. 1998; Poston et al. 1995). In the analysis of PCB cooking loss studies conducted for the Hudson River HHRA, similar observations were reported (TAMS/Gradient 2000).

Combining data from various studies does involve several implicit assumptions:

- Behavior and analytical results for the different COPCs are sufficiently similar that data aggregation is legitimate (which is consistent with EPA's approach);
- Two studies (Hori et al. 2005 and Schecter et al. 1998) provide evidence that cooking loss for dioxin-like PCB congeners may be more similar to that of PCDD/PCDF congeners than non-dioxin-like PCB congeners (see PCB values identified with an asterisk in Table 3);
- Details of the preparation and cooking methods, such as the internal temperature, cooking time, tissue size and geometry, are not critical; and
- Differences between fish species and lipid contents are not significant.

While these assumptions introduce uncertainty, the available data are are too limited for segregation and analysis of each these variables.

Summary

An updated review of the scientific literature identified 17 studies with relevant and appropriate data for quantifying the change in COPC mass in fish tissue as a result of cooking by several methods (deep fry, pan fry, bake/roast, broil/grill, boil/poach, microwave, and smoke). The studies address a variety of fish species, including striped bass, carp, trout, bass, catfish, perch, flounder, salmon, walleye, and bluefish. For the three COPCs included in the analysis (PCBs, dioxins and furans, and DDx compounds), a total of 79 data points were identified for PCB compounds (Aroclor and congener data), 70 data points were identified for DDx compounds, and 12 data points were identified for dioxin and furan compounds (PCDDs and PCDFs).

For each COPC, mass loss was demonstrated regardless of the cooking method used.[3] The amount of COPC mass loss was variable within and between studies, which is likely due to a variety of factors, such as cooking time, temperature, tissue preparation (skinning and trimming) and fillet geometry, lipid content, initial chemical concentration, analytical methodology, and extraction efficiency, which are not consistently controlled for across the various studies. Despite the variability, the data are sufficiently consistent and robust to support inclusion of a quantitative cooking loss factor in the assessment of exposure dose from consumption of fish. Because of the variability in the data, the median may be the

[3] One study (Moya et al. 1998) did not show consistent PCB mass loss following baking and broiling of flounder, however, these results may be an artifact of highly variable initial PCB concentrations. Some studies have also speculated that negative values may be an artifact of incomplete COPC extraction from the raw tissue (Zabik et al. 1982; Sherer and Price 1993).

most appropriate statistic for quantifying cooking loss, because it is the least affected by outliers and extreme values. As noted below, the essential approach used in the data reduction and selection is very similar to that used by USEPA in their derivation of cooking loss factors.

Based on analysis of the available data, estimates of cooking loss for each COPC are as follows:

- **For total PCB mixtures**, cooking loss ranged from no loss to 74% loss across the 14 studies with relevant data. Median losses by cooking method ranged from 25% (bake/roast) to 39% (smoke), with a median of 30% when all PCB data are combined regardless of cooking method.
- **For dioxins, furans and coplanar PCBs**, cooking loss ranged from 28% to 63% across the four studies with relevant data. Median losses by cooking method ranged from 29% (boil/poach) to 57% (bake/roast), with a median of 48% when all dioxin and furan data (except the extreme value of 100%) are combined regardless of cooking method. Combining all dioxin, furan and dioxin-like PCB congener data also results in a median of 48%.
- **For DDx**, cooking loss ranged from 3% to 80% across the ten studies with relevant data. Median losses by cooking method ranged from 22% (boil/poach) to 45% (smoke), with a median of 32% when all DDx data are combined regardless of cooking method.

The CPG's analysis is consistent with how this issue has been evaluated in the past, both by USEPA and others (Bayen et al. 2005; Moya et al. 1998; Salama et al. 1998; Wilson et al. 1998; Sherer and Price 1993; and Zabik and colleagues 1979, 1995, 1995a,b, 1996). Additionally, the analysis reflects an updated data set, including several studies published since the USEPA's analysis for the Hudson River HHRA and the agency's fish consumption advisory guidance (USEPA 2000). Median cooking loss factors identified for dioxins and furans (48%) and DDx compounds (32%) in this analysis are almost identical to those previously identified by USEPA Region 2 for these compounds. As previously noted, Region 2 proposed CTE cooking loss factors of 49% for dioxin, and 30% to 35% for the DDx isomers. For PCBs, however, this updated analysis indicates that USEPA's proposed CTE cooking loss factor of 20% is low; it falls at approximately the 25th percentile of the data set, which is considerable (n=79 data points). Based on this updated analysis, a median cooking loss factor of 30% for total PCBs is supported. For dioxin-like PCB congeners, available data support the use of the same cooking loss factor as that used for PCDDs/PCDFs of 48%. This consistency also makes sense if any risks are assessed on the basis of a dioxin TEQ approach.[4] While chlordane and dieldrin were not specifically included in this analysis, it is expected that median cooking loss factors for these two pesticides are in the same range as DDx (30% to 35%), based on studies where all three compounds have been evaluated (e.g., Zabik et al. 1995a,b, 1996).

[4] Notwithstanding and without prejudice to any objections that CPG may have concerning the use of the TEQ approach to assess potential risks from exposure to coplanar PCB congeners in the LPRSAHHRA.

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Table 1: Overview of Cooking Loss Studies

Study	Chemical(s) evaluated	Species	Source of fish	Cooking method(s)	Was study method appropriate?	Do authors report loss on mass basis?	Was a quantitative estimate of mass loss possible?	Was study used in mass loss calculations?
Armbruster et al. 1987	PCBs	Striped bass	Long Island Sound	Bake, broil, pan-fry, poach, microwave, boil	Yes	No, concentrations before and after cooking reported on dry weight basis	No, data needed to convert results to mass basis not provided	No, but authors report a statistically significant reduction in concentration for 6 cooking methods combined
Armbruster et al. 1989	PCBs	Bluefish	Atlantic Ocean near Long Island Sound	Bake, broil, fry, poach	No, concentration change includes trimming and cooking	No, concentrations before and after trimming/cooking reported on dry weight basis	No, data needed to convert results to mass basis not provided	No, cannot distinguish loss due to cooking alone, but authors report an overall mean reduction of 67%
Bayen et al. 2005	PCBs, DDT	Salmon	Norway	Bake, microwave, boil, pan-fry	Yes	Yes	NA	Yes
Cichy et al. 1979	PCBs	Lake trout	Hancock, MI	Irradiate and broil	No, gamma irradiation used as well as broiling	Yes, percent mass loss due to irradiation and broiling	NA	No, cooking method not relevant to typical cooking practices
Ciereszko and Witczak 2003	PCBs	Carp	Poland	Boil, stew, pan-fry, deep-fry, microwave	Yes	No	No, fillet mass not provided (only % dry weight and lipid)	No
Domingo 2011	PCBs, PCDDs, PCDFs, PAH, HCB, PBDE,	*Review and summary of other published studies.*						No
Hori et al. 2005	PCDDs, PCDFs, and coplanar PCBs	Mackerel	Japan	Grill, boil, tsumire (chopped & boiled fish balls)	Yes	No; authors report "most isomers showed obvious downward trends"	Yes	Yes

Table 1: Overview of Cooking Loss Studies

Study	Chemical(s) evaluated	Species	Source of fish	Cooking method(s)	Was study method appropriate?	Do authors report loss on mass basis?	Was a quantitative estimate of mass loss possible?	Was study used in mass loss calculations?
Karl and Ruoff 2008	TCDD-TEQ and PCB-TEQ	Mackerel and Halibut	Bay of Biscay (mackerel) and Greenland (Halibut)	Hot smoke	Yes	No	Yes	No, results presented on TEQ basis only; actual changes in concentrations obscured by weighting of results on basis of toxicity
Marmon et al. 2009	PCDDs, PCDFs, and PCBs	Herring	Baltic Sea	pH-shift processing	No	No	Possibly, mass balance data provided	No, method not relevant to typical cooking practice
Moses et al. 2009	Pesticides, PCBs, PBDEs	Sheefish	Northwest Alaska	Bake, dry, smoke	Yes	No	No, fillet weight data not provided	No
Moya et al. 1998	PCBs	Winter flounder	New Bedford Harbor, MA	Deep-fry, pan-fry, broil	Yes	Yes	NA	Yes, same data as Poston et al. 1995, which is the original study
Perello et al. 2010	PCDDs, PCDFs, PCBs, and PCDEs	Sardine, Hake, Tuna	Markets in Catalonia, Spain	Pan-fry, grill, boil, roast	No, raw and cooked data appear to be from different groups of fish; also, initial concentrations were close to/at LOD	No	Yes	No, calculating difference between concentrations in cooked fillet from one fish and raw fillet from another fish may not yield accurate estimate of loss, because initial concentrations may not have been similar; also, it is difficult to measure change due to cooking with very low initial tissue concentrations

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Study	Chemical(s) evaluated	Species	Source of fish	Cooking method(s)	Was study method appropriate?	Do authors report loss on mass basis?	Was a quantitative estimate of mass loss possible?	Was study used in mass loss calculations?
Poston et al. 1995	PCBs	Winter flounder	New Bedford Harbor, MA	Deep-fry, pan-fry, broil	Yes	Yes	NA	Yes. Same study as Moya et al. 1998
Puffer and Gossett 1983	PCBs, DDT, Benzo(a)pyrene	White croaker	Santa Monica Bay and Orange County, CA	Pan-fry	Yes	No	Yes, weight loss factor provided	Yes
Reinert et al. 1972	DDT, DDE	Yellow perch, bloaters	Lake Michigan	Pan-fry, bake, broil, smoke	Yes	No	Yes	Yes
Salama et al. 1998	PCBs	Bluefish	Massachusetts waters	Smoke, charbroil, microwave, pan-fry, bake	Yes	Yes	NA	Yes
Schecter et al. 1998	PCDDs, PCDFs, and coplanar PCBs	Catfish	Market in Binghamton, NY	Broil	Author (A. Schecter) reports that raw and cooked samples were all cut from the same fish samples, so concentrations are assumed to be similar	No	Yes, mean weight of catfish samples (n=4) before and after cooking provided	Yes, although some uncertainty associated with of question on internal controls (use of same fish for uncooked and cooked comparsion) and use of mean sample weights
Sherer and Price 1993	PCBs	*Review and summary of other published studies.*						No
Skea et al. 1979	Mirex, Aroclor 1254, DDT	Smallmouth bass, Brown trout	Lake Ontario	Smoke, bake, broil, deep-fry	Yes	Yes	NA	Yes
Smith et al. 1973	Aroclor 1248 and 1254, DDT	Chinook, coho salmon	Manistee River, Michigan	Bake, poach, bake in bag	Yes	No	Yes, fillet weight and % fat in raw and cooked samples provided	Yes

Table 1: Overview of Cooking Loss Studies

Study	Chemical(s) evaluated	Species	Source of fish	Cooking method(s)	Was study method appropriate?	Do authors report loss on mass basis?	Was a quantitative estimate of mass loss possible?	Was study used in mass loss calculations?
Stachiw et al. 1988	2,3,7,8-TCDD	Carp	Saginaw Bay	Roast, charbroil	Study used "restructured carp fillet" (surimi), which involved mechanical deboning & processing of fillets	Yes	NA	Yes
Trotter et al. 1989	PCBs, pesticides	Bluefish	Massachusetts waters	Bake	Yes	No	Yes	Yes
Wang and Harrad 2000	PCBs	Salmon, trout	Not specified	Pan-fry	Yes	Yes, results corrected for mass loss	NA	Yes
Wilson et al. 1998	PCBs and DDT	*Review and summary of other published studies.*						No
Witzcak 2009	PCBs	Herring, salmon, carp, trout, flounder, cod, loach	Market in Szczecin, Poland	Pan-fry	Yes	No	No, fillet weights not provided	No
Witzcak and Ciereszko 2006	PCBs	Mackerel	Norwegian Sea	Smoke	No, sawdust used in smoker contained PCBs	No	No, fillet weights not provided	No, cross contamination from PCBs in sawdust is likely
Witzcak and Ciereszko 2008	PCBs	Herring	Norwegian Sea	Smoke	No, sawdust used in smoker contained PCBs	No	No, fillet weights not provided	No, cross contamination from PCBs in sawdust is likely
Zabik et al. 1979	PCBs, DDT, dieldrin	Lake trout	Lake Superior	Broil, roast, microwave	Yes	Yes	NA	Yes

Table 1: Overview of Cooking Loss Studies

Study	Chemical(s) evaluated	Species	Source of fish	Cooking method(s)	Was study method appropriate?	Do authors report loss on mass basis?	Was a quantitative estimate of mass loss possible?	Was study used in mass loss calculations?
Zabik et al. 1982	PCBs, DDT	Carp	Saginaw Bay	Poach, roast, deep-fry, charbroil, microwave	No, the authors acknowledge issues with extraction from raw fillets	Yes	NA	No, cooking loss estimates from raw fillets in which extraction issues are noted will not provide accurate estimates
Zabik and Zabik 1995	Dioxin	Carp, Salmon, Trout, Walleye, White Bass	Great Lakes	Bake, charbroil, deep fry, pan fry, salt boil, smoke	Yes	Yes	NA	Yes
Zabik et al. 1995a	PCBs, pesticides	Walleye, White Bass	Lake Erie, Huron, Michigan	Bake, charbroil, deep fry, pan fry	Yes	Yes	NA	Yes
Zabik et al. 1995b	PCBs, pesticides	Carp, Salmon	Lake Erie, Huron, Michigan	Bake, charbroil, deep fry, pan fry	Yes	Yes	NA	Yes
Zabik et al. 1996	PCBs, pesticides, PAH	Lake Trout, Siscowets	Lakes Huron, Michigan, Ontario, Superior	Bake, charbroil, salt boil, smoke	Yes	Yes	NA	Yes
Zabik and Zabik 1999	PCBs, PBBs, dioxin	*Review and summary of other published studies.*						No
NA – Not applicable.								

Table 2: Summary of Studies Used for Mass Loss Calculations

Study	Chemical(s) evaluated	Species	Percent Mass Loss						
			Deep Fry	Pan Fry	Bake/Roast	Broil/Grill	Boil/Poach	Microwave	Smoke
Bayen et al. 2005	PCBs, DDT	Salmon	--	PCB 36% (sk-on) 44% (sk-off) DDT 31% (sk-on) 41% (sk-off)	PCB 28% (sk-on) 36% (sk-off) DDT 19% (sk-on) 28% (sk-off)	--	PCB 28% (sk-on) 38% (sk-off) DDT 25% (sk-on) 37% (sk-off)	PCB 23% (sk-on) 30% (sk-off) DDT 21% (sk-on) 29% (sk-off)	
Hori et al. 2005	PCDDs, PCDFs, and coplanar PCBs	Mackerel	--	--	--	PCDD/F 46% PCB 43%	PCDD/F 29% PCB 28%	--	
Moya et al. 1998; Poston et al. 1995	PCBs	Winter flounder	PCB 47%	PCB -17%	--	PCB -15%	--	--	
Puffer and Gossett 1983	PCBs, DDT, Benzo(a)pyrene	White croaker		PCB 29% [i] 65% [j] DDT 39% [i] 74% [j]					
Reinert et al. 1972	DDT	Bloaters (B) Yellow perch (P)	DDT 75%/80% (B) [b] 4% (P)		DDT 6% (P)	DDT 74% (B) 4% (P)			DDT 40% (B)
Salama et al. 1998	PCBs	Bluefish		PCB 27%	PCB 39%	PCB 37% (sk-on) 47% (sk-off)		PCB 60%	PCB 65%
Schecter et al. 1998	PCDDs, PCDFs, and coplanar PCBs	Catfish				PCDD/F 51% PCB 52%			

Table 2: Summary of Studies Used for Mass Loss Calculations

Study	Chemical(s) evaluated	Species	Percent Mass Loss						
			Deep Fry	Pan Fry	Bake/Roast	Broil/Grill	Boil/Poach	Microwave	Smoke
Skea et al. 1979	Mirex, Aroclor 1254, DDT	Smallmouth bass, Brown trout	PCB 74% DDE 75%		PCB 16% DDE 16%	PCB 0% DDE 20%			PCB 27% DDE 27%
Smith et al. 1973	PCBs, DDx	Chinook, Coho salmon			PCB 24%[a] (Chinook) 29% (Coho) DDx[b] 10% (Chinook) 8% (Coho)				
Stachiw et al. 1988	TCDD	Carp (Surimi)			TCDD 63% (covered) 57% (uncov.)	TCDD 62%			
Trotter et al. 1989	PCBs, pesticides	Bluefish			PCB 24% DDE 33%				
Wang and Harrad 2000	PCBs	Salmon (S), Trout (T)		PCB 31% (S, sk on) 30% (S, sk off) 25% (T, sk on) 26% (T, sk off)					
Zabik et al. 1979	PCBs, DDT, Dieldrin	Lake trout			PCB 34% 40% (sk on) 50% (sk off) DDT 30% 47% (sk on) 57% (sk off)	PCB 53% DDT 39%		PCB 26% DDT 55%	

Table 2: Summary of Studies Used for Mass Loss Calculations

Study	Chemical(s) evaluated	Species	Percent Mass Loss						
			Deep Fry	Pan Fry	Bake/Roast	Broil/Grill	Boil/Poach	Microwave	Smoke
Zabik and Zabik 1995	Dioxin	Carp, Salmon, Trout, White bass, Walleye	PCDD/F 47%	PCDD/F 46%	PCDD/F 54%	PCDD/F 48%	PCDD/F 28%		PCDD/F 100%
Zabik et al. 1995a	PCBs, DDx	Walleye (W), White bass (B)	PCB (W) 15% [e] DDT (W) 3% [e]	PCB (B) 18%[c] 44% [d] DDT (B) 32% [c] 38% [d]	PCB (W) 13% [c] 20% [d] 23% [e] DDT (W) 33% [c] 26% [d] 22% [e]	PCB (W) 20% [c] 29% [d] 27% [e] DDT (W) 25% [c] 17% [d] 33% [e]			
Zabik et al. 1995b	PCBs, DDx	Carp (C) Salmon (S)	PCB (C) 16% (sk-on) [c] 32% (sk-off) [c] 67% (sk-on) [d] 32% (sk-off) [d] DDx[b] (C) 29% (sk-on) [c] 40% (sk-off) [c] 38% (sk-on) [d] 45% (sk-off) [d]	PCB (C) 22% (sk-on) [c] 19% (sk-off) [c] 42% (sk-on) [d] 37% (sk-off) [d] DDx[b] (C) 45% (sk-on) [c] 29% (sk-off) [c] 43% (sk-on) [d] 34% (sk-off) [d]	PCB (S) 49% (sk-on) [d] 45% (sk-off) [d] 25% (sk-on) [e] 29% (sk-off) [e] DDx[b] (S) 38% (sk-on) [d] 29% (sk-off) [d] 16% (sk-on) [e] 27% (sk-off) [e]	PCB (S) 40% (sk-on) [d] 62% (sk-off) [d] 61% (sk-on) [df] 52% (sk-off) [df] 44% (sk-on) [e] 33% (sk-off) [e] 37% (sk-on) [ef] 44% (sk-off) [ef] DDx[b] (S) 39% (sk-on) [d] 58% (sk-off [d] 57% (sk-on) [df] 56% (sk-off) [df] 45% (sk-on) [e] 24% (sk-off) [e] 41% (sk-on) [ef] 40% (sk-off) [ef]			

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Table 2: Summary of Studies Used for Mass Loss Calculations

Study	Chemical(s) evaluated	Species	Percent Mass Loss						
			Deep Fry	Pan Fry	Bake/Roast	Broil/Grill	Boil/Poach	Microwave	Smoke
Zabik et al. 1996	PCBs, DDx	Lake Trout (T) Siscowets (St)			PCB (T) 18% [d] 10% [e] 11% [g] 18% [h] DDx[b] (T/St) 14% [d] 10% [e] 36% [g] 26% [h]	PCB (T) 15% [d] 7% [e] 12% [g] 32% [h] DDx[b] (T) 20% [d] 14% [e] 36% [g] 32%	PCB (T/St) 10% [e] 19% [h] DDx[b] (T/St) 4% [e] 19% [h]		PCB (T/St) 41% [e] 37% [h] DDx[b] (T/St) 56% [e] 50% [h]

Notes:

a First value for frying in lard, second value for frying in corn oil
b DDx mass loss was calculated by taking the average of mass loss values reported for DDE, DDE, and DDT (which are averages of replicates).
c Lake Erie
d Lake Huron
e Lake Michigan
f Charred and scored
g Lake Ontario
h Lake Superior
i Orange County
j Santa Monica

Table 3: Summary Statistics and Outlier Analysis

PCBs	DDx Compounds
0.15	0.03
0.16	**0.80**
0.32	**0.75**
0.67	0.04
0.32	**0.75**
0.74	0.29
0.47	0.40
0.65	0.38
0.29	0.45
0.27	**0.74**
0.18	0.39
0.44	0.32
0.22	0.38
0.19	0.31
0.42	0.41
0.37	0.45
0.36	0.29
0.44	0.43
0.31	0.34
0.30	0.30
0.25	0.47
0.26	0.57
-0.17	0.33
0.24	0.26
0.34	0.22
0.40	0.10
0.50	0.10
0.39	0.19
0.23	0.28
0.20	0.06
0.13	0.16
0.49	0.38
0.45	0.29
0.25	0.16
0.29	0.27
0.18	0.14
0.10	0.10
0.11	0.36
0.18	0.26
0.28	0.33
0.36	0.25
0.16	0.17
0.29	0.33
0.14	0.39

Dioxin Compounds
0.47
0.46
0.54
0.63
0.57
0.48
0.51
0.46
0.62
0.28
0.29
1.00

Outlier
Extreme Value
* Dioxin-like PCB

Cooking Method Key
Deep Fry
Pan Fry
Bake/Roast
Broil/Grill
Boil/Poach
Microwave
Smoke

PCBs	DDx Compounds
0.37	**0.74**
0.47	0.04
0.53	0.20
0.20	0.39
0.29	0.58
0.27	0.45
0.40	0.24
0.62	0.20
0.44	0.14
0.33	0.36
0.15	0.32
0.07	0.57
0.12	0.56
0.32	0.41
0.61	0.40
0.52	0.25
0.37	0.37
0.44	0.04
0.00	0.19
-0.15	0.55
0.43*	0.21
0.52*	0.29
0.10	0.40
0.19	0.27
0.28	0.56
0.38	0.50
0.28*	
0.60	
0.26	
0.23	
0.30	
0.65	
0.41	
0.37	
0.27	

	PCBs	DDx Compounds	Dioxin Compounds	
Median	0.30	0.32	0.50	Median
Mean	0.32	0.34	0.53	Mean
Std. Dev.	0.17	0.18	0.18	Std. Dev.
Count	79	70	12	Count
Minimum	-0.17	0.03	0.28	Minimum
10th Percentile	0.13	0.10	0.31	10th Percentile
25th Percentile	0.20	0.21	0.46	25th Percentile
50th Percentile	0.30	0.32	0.50	50th Percentile
75th Percentile	0.42	0.41	0.58	75th Percentile
90th Percentile	0.53	0.57	0.63	90th Percentile
Maximum	0.74	0.80	1.0	Maximum

Table 3 (cont.)	PCBs	DDx Compounds	Dioxin Compounds	
IQR (75th - 25th)	**21.56**	**19.74**	**11.58**	**IQR (75th - 25th)**
1.5 * IQR	32.34	29.61	17.36	1.5 * IQR
75th + 1.5*IQR	74.69	70.60	75.31	75th + 1.5*IQR
25th - 1.5*IQR	-11.56	-8.37	29.01	25th - 1.5*IQR
3 * IQR	64.69	59.23	34.73	3 * IQR
75th + 3IQR	107.04	100.21	92.68	75th + 3IQR
25th - 3IQR	-43.90	-37.99	11.64	25th - 3IQR

Table 4: Cooking Loss Statistics with and without Extreme Values and Outliers

	PCBs		DDx Compounds		Dioxins and Furans	
	All Data	**w/o Outliers [(a)]**	**All Data**	**w/o Outliers [(b)]**	**All Data**	**w/o Extreme Value [(c)]**
Median	30	30	32	31	50	48
Mean	32	33	34	31	53	48
Count	79	77	70	65	12	11
Minimum	-17	0	3	3	28	28
10th Percentile	13	15	10	10	31	29
25th Percentile	21	23	21	20	46	46
50th Percentile	30	30	32	30	51	48
75th Percentile	42	43	41	40	59	55
90th Percentile	53	54	57	49	63	62
Maximum	74	74	80	58	100	63

Notes:
(a) - No extreme values were identified in the PCB data set; two negative values were identified as outliers.
(b) - No extreme values were identified in the DDx data set; five high-end values were identified as outliers.
(c) - One extreme value (100% loss) was identified in the dioxins and furans data set; no outliers were identified.

Figure 1: Identification of Outliers and Extreme Values

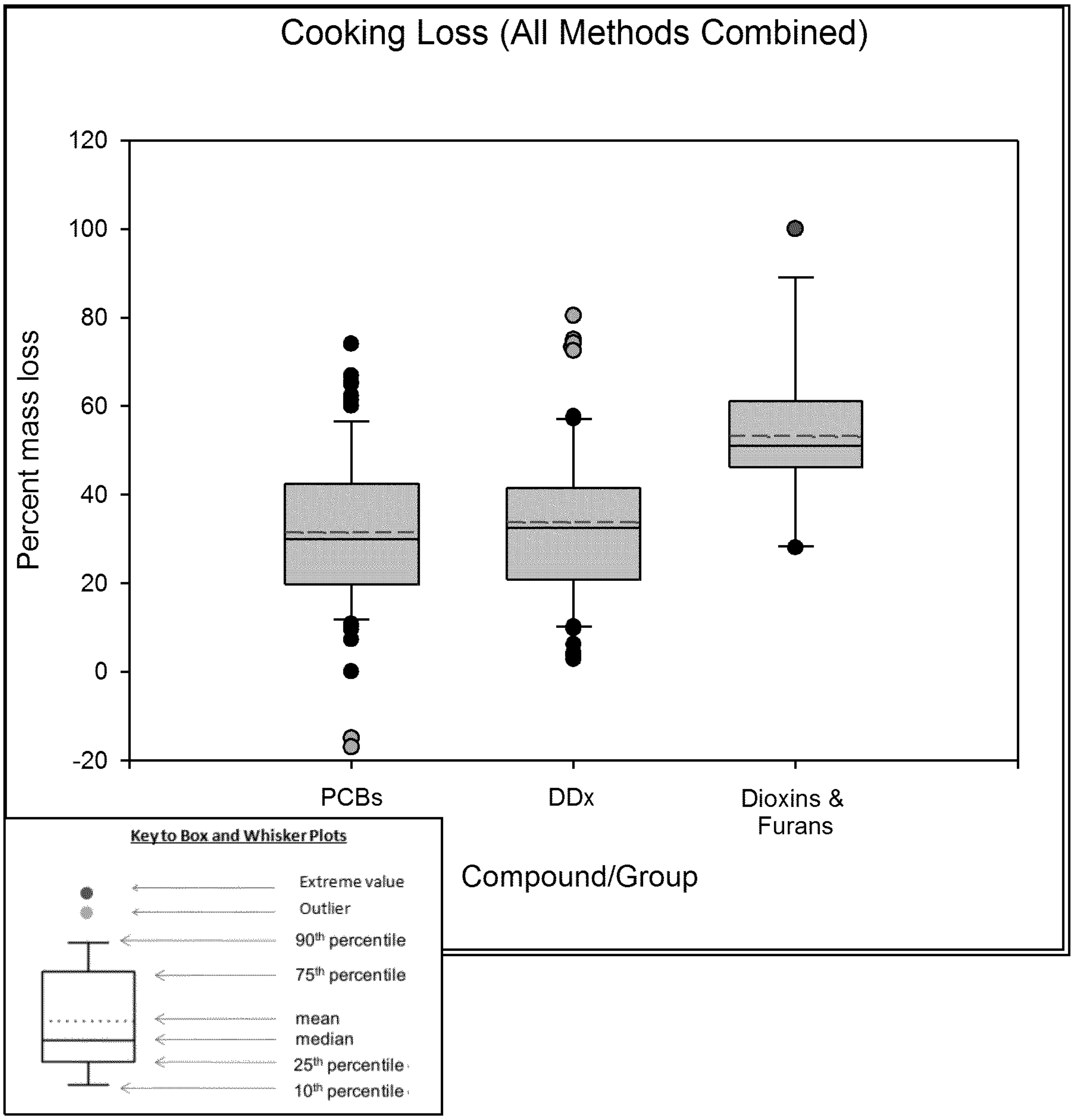

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Figure 2: Summary of Mass Loss by COPC and Cooking Method